Should *JRC* Be Used to Assess Rock Joint Hydro-Mechanical Behavior? Perspectives Derived From 3D-Printed Joint Aperture Measurements

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Abstract: The objective of this investigation is to address a critical inquiry: Is the joint roughness coefficient (JRC) an appropriate metric for assessing the hydro-mechanical behavior of smooth to slightly rough rock joints? We employed 3D printing technology to create matched and mismatched joints with similar surface configurations (profiles) and joints with the same JRC values but varying surface configurations, subsequently measuring the mechanical and hydraulic apertures (E and e). A new and easy way to make joint profiles with regulated joint surface roughness (JRC = 3.5–5.8) was suggested, and the 3D-printed joint surfaces were very near to the required JRC values. The stress-dependent E and e of 3D-printed joint samples with defined surface configurations and JRC values were measured and fitted using a semi-logarithmic closure model, demonstrating unique trends for matched and mismatched joints. This research elucidates the application of the JRC in forecasting stress-dependent apertures, specifically by differentiating its predictive efficacy (variability) in matched versus mismatched joints with both identical and divergent surface configurations. The study decouples the effects of matedness, asperity geometry, and roughness magnitude, demonstrating that while JRC is a reliable indicator for mismatched joints, it inadequately reflects aperture variability in matched joints (within the JRC range of 3–5), where surface geometry and matedness are predominant factors. This study not only presents a reproducible technique for joint construction but also elucidates the limitations of JRC as an independent descriptor, highlighting the necessity to integrate surface configuration and joint matedness into forthcoming hydro-mechanical models.

Keywords: ***Mechanical/hydraulic aperture, 3D-printed joints, Joint roughness coefficient (JRC), Matched/mismatched joint, Stress dependence.***

Introduction

Joint roughness critically influences the hydro-mechanical behavior of rock masses, affecting stability and fluid flow. The JRC is widely used to characterize joint surfaces; however, its adequacy as a sole descriptor is questionable, especially for matched joints where surface compatibility (matedness) might play a crucial role. This study examines the combined effects of JRC, matedness, and surface configuration on stress-dependent mechanical and hydraulic apertures of rock joints with smooth to slightly rough surfaces (JRC = 3.5–5.8).

Methodology

We fabricated matched and mismatched rock joint samples using 3D printing, precisely controlling surface roughness (JRC = 3.5–5.8) and configurations (Figure 1). MATLAB-designed surfaces were converted to 3D models in AutoCAD and printed into cylindrical specimens (25 mm diameter, 50 mm height). Surface roughness was verified via 3D laser scanning.

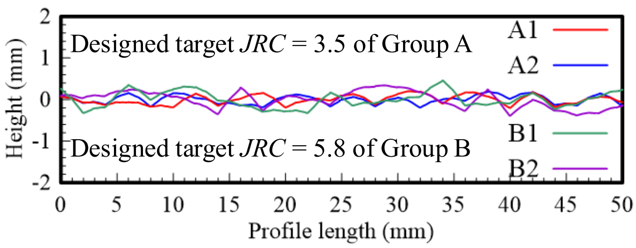

Figure 1, The designed configurations: for model A (A1 and A2 with designed target JRC = 3.5) and for model B (B1 and B2 with designed target JRC = 5.8).

Mechanical and hydraulic apertures were measured under normal stresses from 1 to 30 MPa using the YOKO2 system. Hydraulic apertures were estimated from helium gas flow data applying the cubic law, while mechanical apertures were derived volumetrically based on Boyle's law. Aperture closure trends were analyzed with a semi-logarithmic model.

Results and Discussion

Distinct behaviors emerged between matched and mismatched joints. Matched joints showed limited sensitivity to JRC but substantial sensitivity to surface configuration, while mismatched joints exhibited strong dependence on JRC, highlighting larger apertures and lower stiffness characteristics. Comparative analysis with granite joint behaviors from literature affirmed the validity of 3D-printed samples as suitable analogs for natural rock.

The $\Delta E - e$ (joint closure vs. hydraulic aperture) relationship was consistent across matched joint samples regardless of JRC or asperity details, while mismatched samples exhibited significant variability intensified by increasing roughness (Figure 2). Modeling using Zimmerman et al. (1992)'s contact-area framework revealed joint contact area ratios of ~0.70 for matched joints and ~0.15 for mismatched joints, paralleling observed aperture responses under stress. Findings demonstrate that matched joint aperture behaviors are predominantly governed by surface geometry and contact morphology rather than JRC alone. In mismatched joints, JRC significantly affects aperture variability, indicating greater asperity mismatch influence on hydraulic and mechanical behavior.

Conclusions

Le et al. (2025) found that JRC alone cannot characterize the hydro-mechanical behavior of matched rock joints in the low JRC range (3–5). Predictive models must include surface asperity configuration and matedness because they strongly affect stress-dependent aperture variability. JRC is reliable for mismatched joints where roughness dominates response. To properly apply laboratory findings to field situations, future research should use more representative joint materials and a larger JRC spectrum.

References

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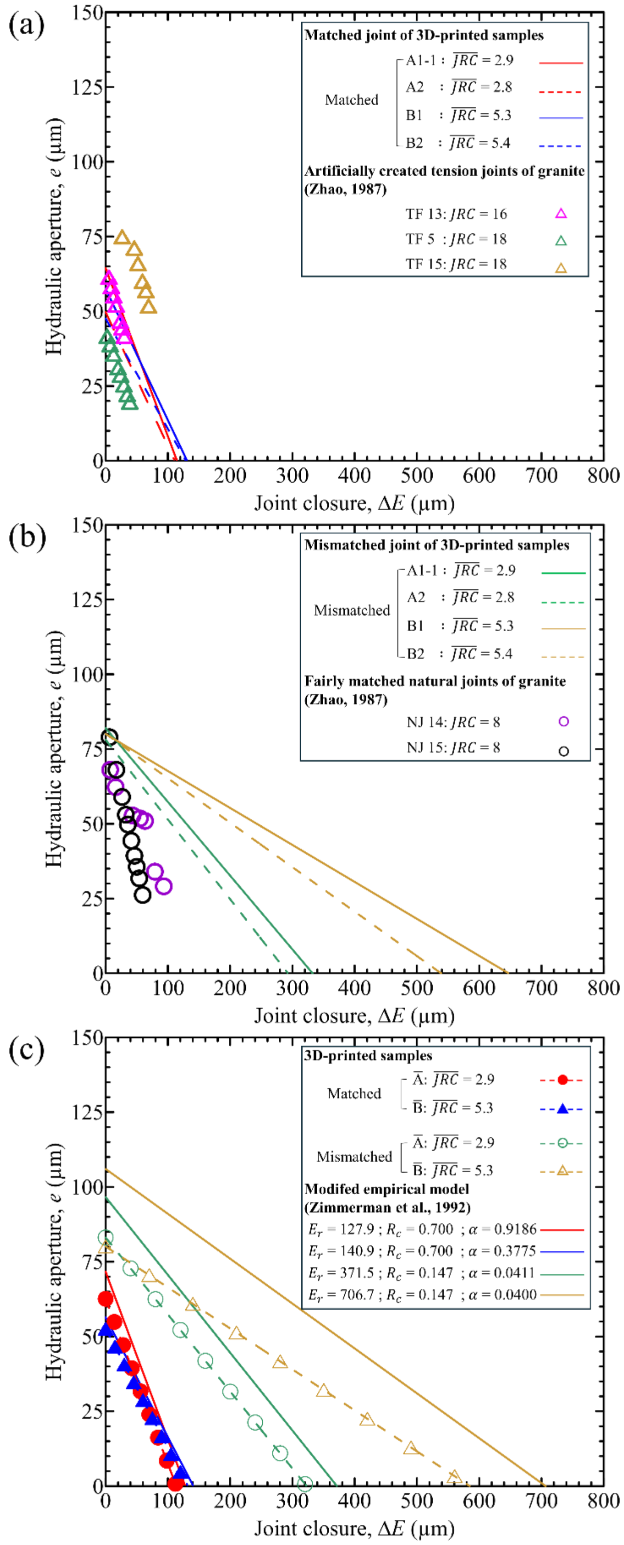

Figure 2, The relation between joint closure and hydraulic aperture during first loading cycle ($\Delta E - e$ relation): (a) The fitting model of 3D printed matched joints are compared with Zhao's (1987) matched artificially created tension joints of granite; (b) The fitting model of 3D printed mismatched joints are compared with Zhao's (1987) fairly matched natural joints of granite; (c) Using the model of Zimmerman et at. (1992) (solid curves) to analog $\Delta E - e$ relation from our experimental data of 3D-printed matched and mismatched joints (dashed curves with symbols).